

MR Neurography - Imaging Peripheral Nerves

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MR imaging of peripheral nerves not only allows sensitive detection of peripheral nerve abnormalities but also displays high detail of regional anatomy and improves specificity of diagnosis. The use of MR imaging for diagnosis and evaluation of peripheral nervous system disorders was initially reported in the late 1980's. Since then, expertise gained through experience over the last decade coupled with improvements in MR imaging technology now make routine evaluation of major peripheral nerves possible including nerves within the brachial and lumbosacral plexuses as well as major peripheral nerves in the upper and lower extremities. MR nerve imaging, also referred to as MR neurography (MRN), allows separation between normal and abnormal peripheral nerves. More importantly, MRN often enables more sensitive and specific diagnoses to be made that help to separate operable from inoperable lesions. MRN also helps to better localize the principal site of nerve involvement and to better define the extent of involvement that is essential for preoperative planning in those lesions that may be amenable to surgical treatment.

Technique

MR imaging of the peripheral nervous system requires high resolution imaging techniques. The largest peripheral nerve in the body is the sciatic nerve, which normally measures between 10 and 15 mm in cross sectional size. The major nerves to the upper and lower extremities are considerably smaller, often measuring only 2 to 3 mm in cross sectional dimension. Thus, visualization of these small nerves that allows definition of substructure within the nerve requires high-detailed images. Thus, the combination of thin slices, the smallest practical FOV required to image a specific body part and a matrix size adequate to yield small cross sectional pixel areas are combined to provide high resolution images. In general, inplane cross sectional pixel dimensions of approximately 500 microns and a slice thickness of 3 to 4 mm are generally obtained. For an FOV of approximately 16 cm or less, a matrix size of 256x256 is generally adequate. For larger fields of view in the range of 20 to 25 cm a 512x512 matrix is often utilized. In order to provide good SNR for these high-resolution images, phased array surface coils are essential for peripheral nerve imaging. In general, one should use the smallest available phased array coil that most closely matches the size of the body part being imaged. For example, imaging of the median nerve in the carpal tunnel or the ulnar nerve in the cubital tunnel is ideally done with coils of a very small size that encompass the region of interest. Imaging of the radial, ulnar or median nerves in the arm will require coils of moderately larger size in order to encompass the requisite FOV while still maintaining good SNR. Imaging of the sciatic nerve in the thigh will require a still larger RF coil

set. Imaging of the brachial plexus or the lumbosacral plexus will require the largest phased array coils to encompass these regions of interest at the neck and shoulders or in the pelvis, respectively.

Pulse Sequences

The imaging protocol for peripheral nerve evaluation generally includes a T1-weighted set of images to provide good anatomical definition of regional muscles, blood vessels and nerves outlined by perineural and intermuscular fat. A T2 imaging sequence is also obtained that consists of either a conventional T2-weighted fast spin echo image with chemical shift selective fat saturation or a short tau inversion recovery (STIR) image. T2-weighted images with fat saturation provide higher SNR compared with STIR images but lower conspicuity for abnormal signal change within the nerve. STIR imaging is often preferred because of its higher conspicuity for abnormal nerve signal. However, STIR imaging also has its limitations. The disadvantages of STIR include the fact that there is generally lower SNR compared with T2-weighted spin echo sequences and STIR images are also degraded by pulsatile flow artifacts from regional arteries and veins. To partially compensate for this, presaturation flow suppression pulses are applied at the proximal and distal limits of the imaging volume in order to reduce signal from in-flowing blood.

Image Interpretation

Interpretation of peripheral nerve images is optimized by direct comparison of T1 and fat saturated T2 or STIR images. The T1 images provide anatomical detail of the regional nerves, muscles and bones while fat saturated long TR images tend to obscure anatomical landmarks since fat saturation renders most structures a relatively uniform intensity of gray. By comparing T1 images obtained in the same plane and with the same centering and FOV, one can visually co-register the images to identify the nerves and other key structures on the fat saturated T2 images. In some cases, multiplanar reformatting is done in oblique planes to obtain an image that provides better visualization of nerve continuity.

Muscle Imaging

Imaging of the regional musculature innervated by the nerve or nerves of interest provides a valuable adjunct for the diagnosis of peripheral nerve disease. The presence of increased T2 signal intensity that anatomically conforms to a specific muscle or group of muscles is indicative of denervation and, when present, helps to confirm the presence of peripheral nerve injury or disease. The pattern of muscles showing denervation will help to identify the nerve or nerves involved. It often will also help to identify the site of nerve involvement if the lesion is focal or the most proximal extent of nerve involvement if the disease process is more diffuse. Evaluation for evidence of denervation is always done on the MRN images obtained for peripheral nerve evaluation. In some cases, however, additional images may be performed when the initial nerve imaging study is equivocal and the clinical examination does not adequately localize the site of

nerve abnormality. Supplemental muscle images may be done to better identify the site of peripheral nerve abnormality using lower resolution techniques that provide a higher SNR to better identify abnormal T2 signal changes within denervated muscles.

Structure of Peripheral Nerve

Peripheral nerves have a complex internal structure. The basic unit forming the peripheral nerve is the axon. Peripheral nerves have three connective tissue compartments that support and protect the complex nerve structure. The innermost compartment is the endoneurium, which consists of loose vascular connective tissue and extracellular fluid. The endoneurium invests the Schwann cell-axon complex. Multiple axons, their Schwann cell layers and encircling endoneurium are bundled together into structures called fascicles. Each fascicle is wrapped by a dense perineurial sheath. Blood supply to the axonal structures is supplied through capillaries in the endoneurial space. Circulating blood is isolated from the endoneurial fluid space by tight junctions between the capillary endothelial cells that form a blood-nerve barrier that is analogous to the blood-brain barrier. The epineurium is the third and outermost connective tissue compartment of the nerve. The epineurium consists of dense irregular connective tissue with thick collagen and elastin fibers that envelopes the periphery of the nerve and forms the encircling peripheral nerve sheath. It provides mechanical support for the nerves when they are subjected to movement and stretching forces. Variable amounts of interfascicular adipose tissue (loose perineurium) are present within larger nerves and this helps to outline and define fascicular structure within these nerves on high resolution, T1-weighted MR images. The endoneurial fluid present within each fascicle is felt to be largely responsible for our ability to image fascicular structure on T2-weighted, fat saturated, high resolution MR images of peripheral nerves.

Role of MR nerve imaging

MR peripheral nerve imaging can provide valuable information not obtainable in any other way. The ability to visualize anatomical definition of a nerve and its relation to surrounding structures is essential. The morphologic appearance of an affected nerve can help to narrow the differential diagnosis or, in some cases, can result in a specific diagnosis. In addition to diagnostic considerations, MRN is essential for invasive treatment planning. If a patient is being considered for surgical therapy, definition of regional anatomy is needed for the surgeon to perform accurate preoperative planning. MR imaging, similar to electrophysiologic studies, can often confirm the presence of a peripheral nerve abnormality that is the likely etiology for a patient's symptoms. It also helps to define the site and extent of abnormal nerve involvement. Post treatment evaluation of patients with prior tumor removal or with other peripheral nerve disorders who now present with recurrent symptoms are also best evaluated with MR nerve imaging. The MRN studies can best evaluate response to therapy, completeness of removal of a tumor, the presence of tumor recurrence or re-entrapment of a previously treated entrapment neuropathy. Detection of

complications of therapy such as radiation injury to a nerve or plexus are also best evaluated with MRN.

Abnormal nerves

T2-weighted images help define whether a peripheral nerve displays normal or abnormal signal intensity and one should not rely solely on the size and appearance of the nerve on T1-weighted images. Diffuse or focal enlargement of a nerve, on the other hand, is definitely abnormal. Such enlargement is usually also accompanied by hyperintensity on T2-weighted images. It is important to note that increased hyperintensity of the nerve on T2-weighted images is abnormal even in the absence of nerve enlargement or a mass lesion. The assessment of abnormal T2 hyperintensity is subjective, however, and is most accurately interpreted when the interpreting physician has gained a base of experience in recognizing normal and abnormal signal changes in peripheral nerves. In cases where interpretation may be uncertain the diagnosis can be aided by imaging of the corresponding nerve on the opposite side (assuming that this site is asymptomatic) or by imaging of the distal musculature to look for signs of denervation.

In cases of compressive neuropathies, focal hyperintense T2 signal may be observed in the affected nerve at the site of compression while the nerve proximal and distal to the site of compression may be normal in signal intensity. The pathogenesis for this focal change is not known but it may represent either an increase in endoneurial fluid or a focal area of demyelination. The latter may demonstrate increased T2 signal change analogous to that seen with demyelinating white matter lesions in the brain. The entrapped nerve may also show changes in configuration, such as proximal swelling and/or flattening at the site of compression.

Another pattern that helps define abnormality within a nerve is a distortion in the fascicular pattern of the nerve. In some abnormal nerves there may be variable swelling of individual fascicles that results in an inhomogeneous appearance of fascicles on cross sectional imaging of the nerve. These changes are virtually always accompanied by a marked increase in T2 signal intensity although we have seen some cases where the signal intensity change was present in some, but not all, of the fascicles within a cross sectional image of the nerve.

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